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Dimming the NCL30002 LED Driver



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APPLICATION NOTE

In principle, dimming LEDs is quite simply a matter of reducing the drive current. There are no special conditions to observe such as present in dimming arc discharge lighting. Continuous dimming (reducing the DC current) and PWM dimming (turning the LED on-off from a fixed current to zero current) techniques both work very well with LEDs. Reducing the DC current has a slight nonlinearity due the change in efficacy of the LED with operating current while PWM dimming is extremely linear.

In the general lighting world, these two techniques are starting to become adopted for new or retrofit installations using LED lighting. The vast majority of installations that

employ dimming use the venerable phase control dimmers. Phase control dimmers have been widely used for incandescent lighting for almost 50 years. They could be described as a type of PWM dimming. The on time is variable over the half cycle of the AC input which varies the average voltage applied to the load (generally incandescent lights). The conduction time is varied by delaying the turn on of the series switching device. The switching device is usually an SCR or TRIAC. Both of these devices are triggered on by a current pulse to their gate and turned off when their current drops below the holding current of the device. A typical output waveform is shown in Figure 1.

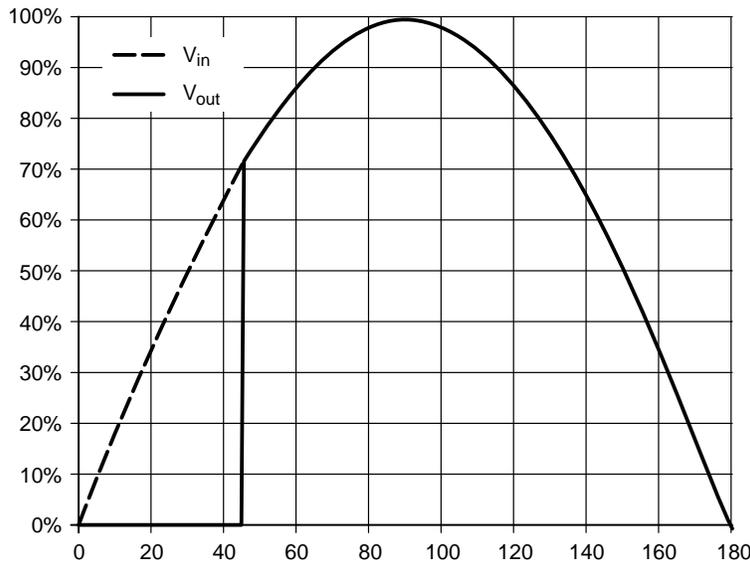


Figure 1. Typical Voltage versus Conduction Angle

The time that the leading edge is delayed to turn on is the adjusted variable. The current drops to zero at every half cycle so the switching device naturally commutates.

This dimming control technique becomes much more complicated when the load is not predominantly a resistor. Unfortunately this is almost every load that is not an incandescent light or a resistive heating element (as you may have guessed, this is also the type of controller used in electric stoves). On the plus side, phase control techniques

are simple, efficient and low cost. On the minus side, they are not readily compatible with any modern type of high efficacy lighting and create large line harmonics which cause losses in the power distribution infrastructure. Unlike most of the world, the US has relatively robust infrastructure so the losses from harmonics are not as large a concern as Europe for example.

There are many reasons to make modern lighting backward compatible.

1. Regulatory – ENERGY STAR® requirements recognize the need for manufacturers to state if an LED bulb is dimmable or not
2. Market Acceptance – making new products backward compatible lowers the barrier to acceptance.

The Issues with Phase Control Dimmers

For the purposes of this paper, we are addressing leading edge phase control dimmers (which is by far the largest segment). There are some trailing edge phase control dimmers that turn off part way through the line cycle. These have different types of switches than conventional SCRs and TRIACs. Trailing edge dimmers are more compatible to non-resistive loads but are not commonly used since they are more complex and costly.

There are three main issues that need to be addressed:

1. Premature commutation
2. Holding current minimum
3. Leakage current

Design Example Specifications

For the purposes of this discussion, let’s consider an LED driver based on the NCL30002 with the following design specifications:

- Input Voltage – 100 V ac – 132 V ac
- Output Voltage – 22 V dc – 26 V dc
- Output Current – 750 mA dc
- Efficiency – 85%

Premature Commutation

All lighting, except incandescent lighting, requires some type of regulating circuit to connect to the mains power. Today those interface circuits use high frequency switching regulators for size reduction and efficiency improvements. Consequently, they all have EMI filters to suppress conducted EMI. The EMI filter consists of inductors and capacitors. As you see in Figure 1, the voltage rises rapidly part way through the line cycle. This step of voltage causes ringing of the EMI filter components. The current rises sharply and then tends to ring negative. This is seen in Figure 2.

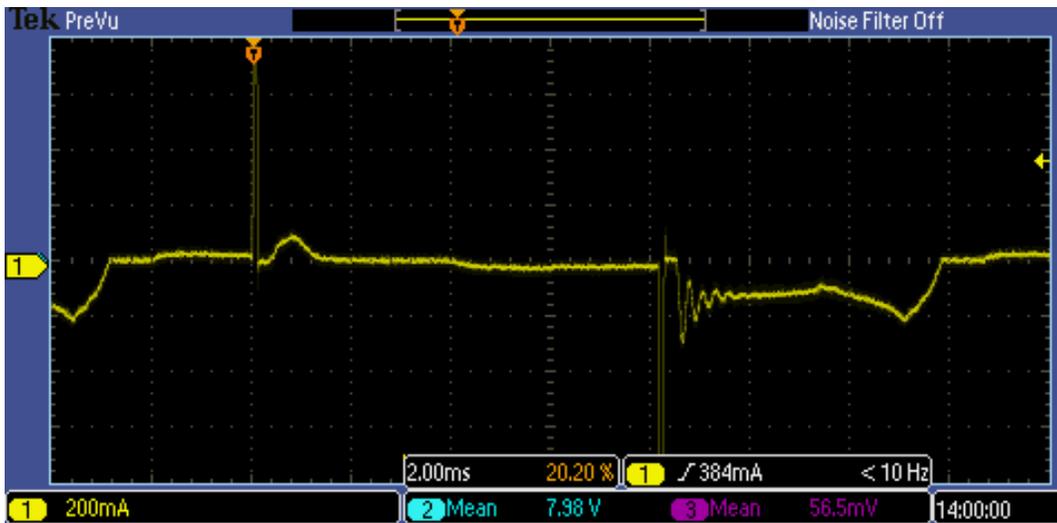


Figure 2. Typical Input Phase Dimming Current to an Electronic LED Driver Without Preconditioning

On the positive half cycle, the ring back commutates the TRIAC completely turning off the dimmer. On the negative half cycle, the ring back is clearly seen but the TRIAC does not commutate. This demonstrates the asymmetrical nature

of TRIACs. This asymmetry can show up at the line rate as flicker. Figure 3 shows another case where the TRIAC tries multiple times per cycle to start but to no avail.

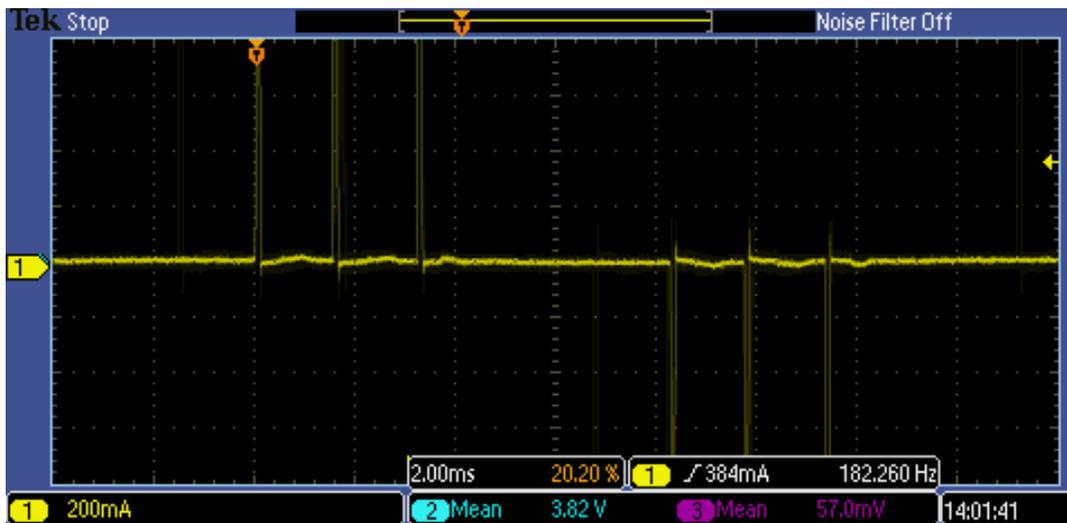


Figure 3. Typical Input Phase Dimming Current to an Electronic LED Driver Without Preconditioning

The key to solving the commutation problem is to assure that the current does not ring in opposite polarity when the dimmer starts conducting. High start current is actually good for assuring a good start for the TRIAC however, the current must be continuous in the same polarity. In some cases it's possible to do this by proper selection of EMI filter

components. Generally this requires the inductors to be large and the capacitors to be small. The open loop architecture of the NCL30002 driver complicates this approach due to its partial negative impedance characteristic. This is discussed in Application Note AND9094/D. An active inrush limiting circuit shown in Figure 4 accomplishes the goals.

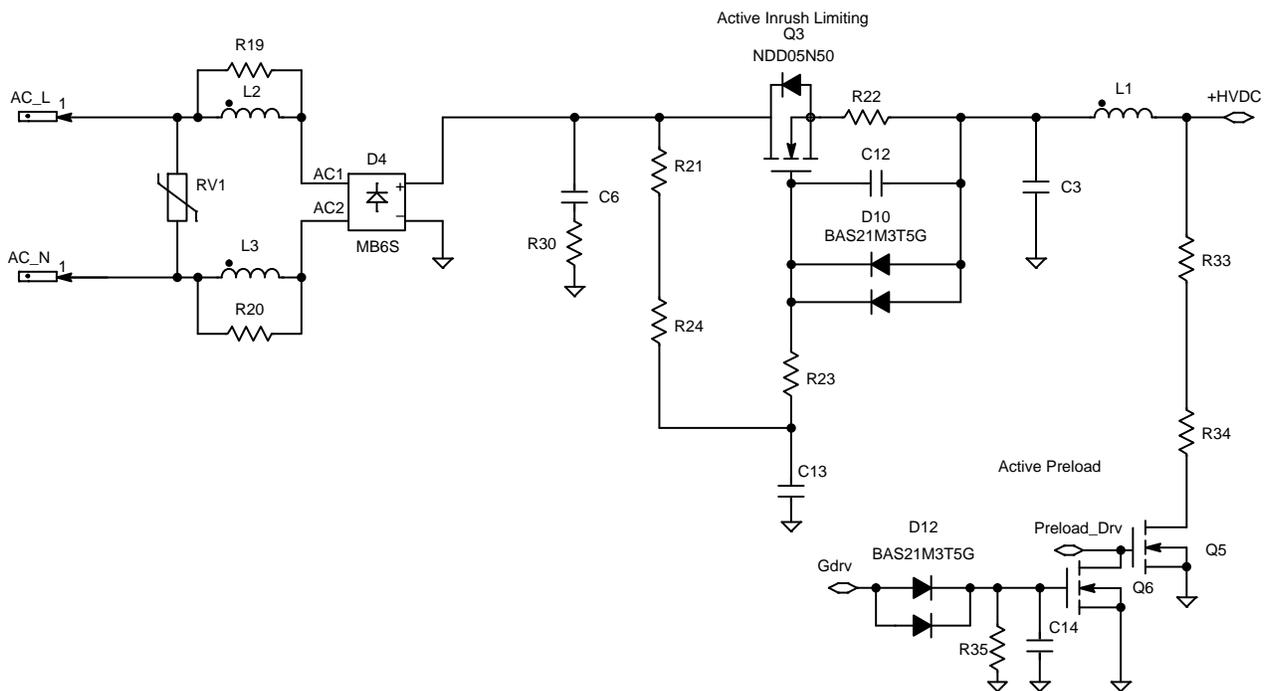


Figure 4. Active Inrush Limiter

This is a source follower that limits the dV/dT applied to the EMI filter. R21, R24, and C13 set the time constant for the rate of rise of voltage. R22 degenerates the follower gain

for stability and provides a maximum current limit. The results are seen in Figure 5.

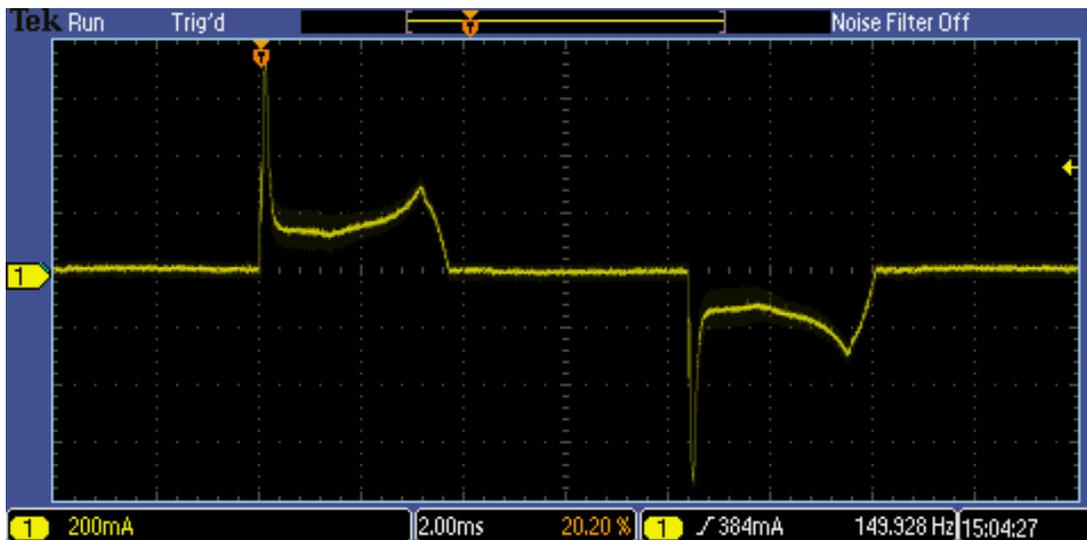


Figure 5. Input Current with Active Inrush Limiter

The ring back is completely gone and dimmer's TRIAC conducts normally. By limiting the peak current into the LED driver, this reduces stress on the triac dimmer and reduces the peak load seen by the dimmer allowing more LED lamp loads to be driven from one dimmer.

Holding Current

The switching device inside the dimmer has a minimum holding current. Below the holding current, the device is not guaranteed to stay on. Unfortunately there is nothing that the driver designer can do to fix this. It's not uncommon for dimmer manufacturers to specify a minimum wattage for proper operation. Multiple loads can be paralleled on a single dimmer to meet the minimum. This is the likely case for an installation. Also it is possible to mix devices on a single dimmer. One could have LED and incandescent loads on one dimmer.

Off State Pass Through Current

TRIAC dimmers are active devices that require a certain amount of even when the dimmer is off or in a low state where the bulb is no longer illuminated. The pass through current varies considerably between manufacturers and dimmer type. Some dimmers have built in night lights to see the switch location in the dark while other "digital dimmers" have an embedded micro-controller that stores the dimmer setting and steals some current from the line all the time to keep alive. There are no standards that specify the limits of the pass through current and this can be AC or DC pulses which further complicates the problem.

There is also operating current at the extreme low end of the dimming range and in the case of lit and smart dimmers, when the dimmer is actually off. At some point there is insufficient voltage to operate the driver. The driver will drop out at this point. So when the dimmer is in a very low state or when OFF, current will continue to flow and the dimmer will charge the input capacitance and depending on the magnitude of the current and the parasitic losses in the drive circuitry, it is possible that the driver attempts to restart. With insufficient voltage the driver will once again drop out. This cycling on-off will continue infinitely unless the driver can provide a path for the operating current guaranteeing some hysteresis. An active preload is added to provide such a path for the dimmer operating current. The preload is on until the driver starts switching. The gate drive from the NCL30002 peak charges an RC network to a FET (Q6) which turns off the preload so the efficiency is not degraded. A second benefit of this period circuit is that it improves the pop-on performance of the dimmer.

Dimming Curve Matching

Since incandescent lamps are the incumbent technology, we are obliged to match their dimming performance when installed on a dimmer. In the United States, NEMA, the National Electronics Manufacturing Association, has developed a recommended dimming curve mask intended to emulate the profile of an incandescent lamp which is shown in Figure 6.

AND9096/D

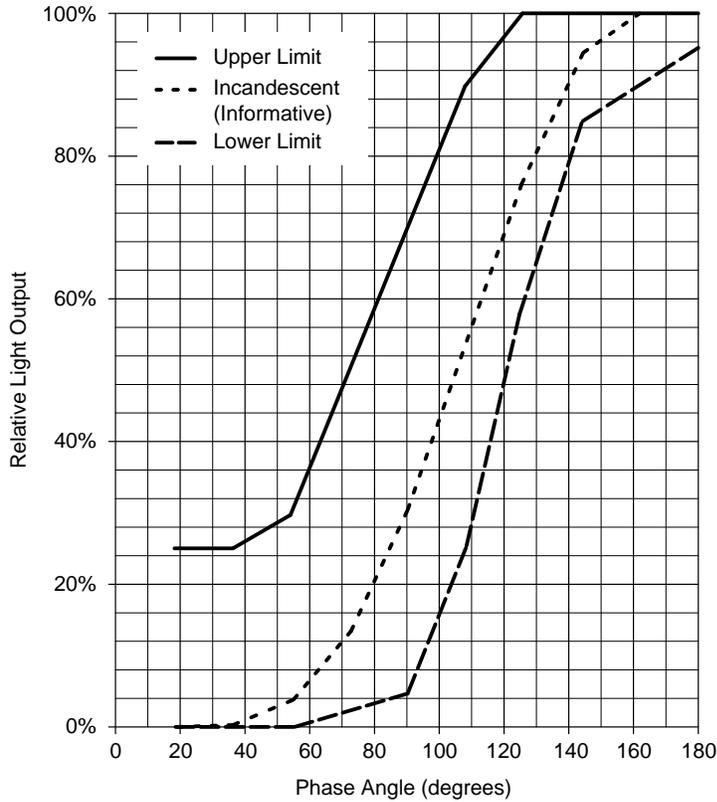


Figure 6. NEMA SSL-6 Phase Control Dimming Curve

Incandescent lamps do not respond very linearly with the phase angle. This requires us to make some curve fitting to make the LED driver behave more like an incandescent in

dimming. Without some acceleration at the lower part of the dimming curve the output would be rather linear looking as in Figure 7.

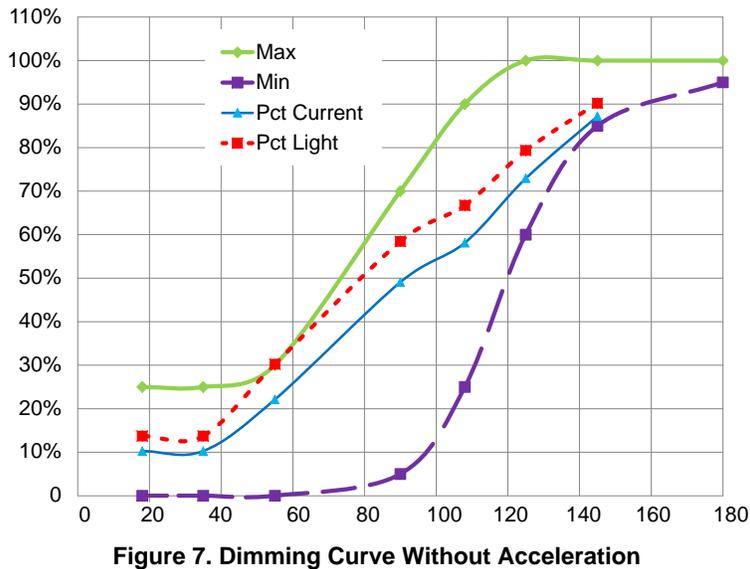


Figure 7. Dimming Curve Without Acceleration

AND9096/D

The NCL30002 has two circuits which have opposite effects on the output current. The dimming accelerator is based on the average input voltage which has the same effect as reducing

the input voltage. However, the feed forward control tries to correct for line regulation. The acceleration circuit shown in Figure 8 gives a better looking curve as shown in Figure 9.

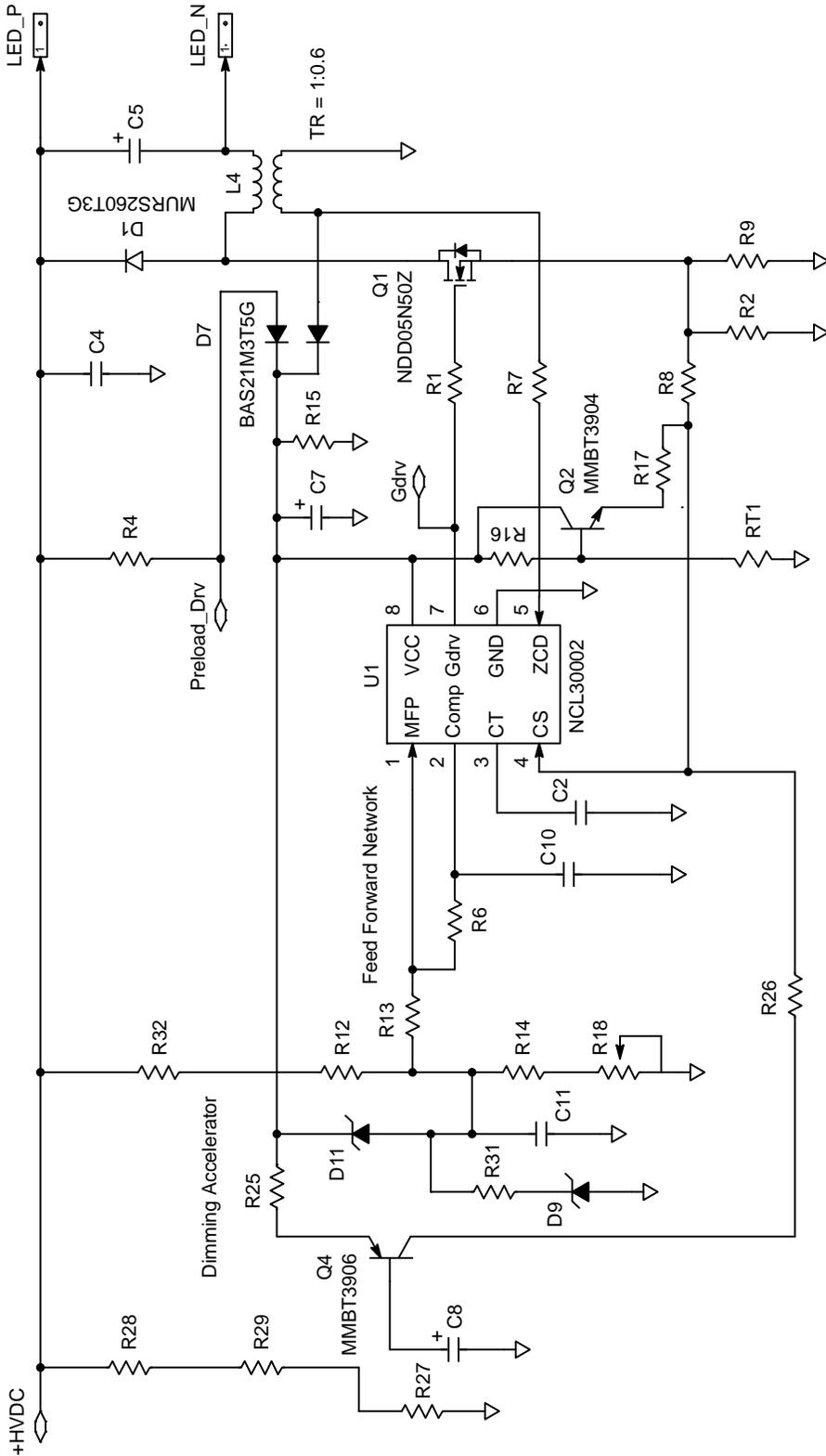


Figure 8. Dimming Acceleration Schematic

AND9096/D

The circuit is simplified by removing some parts for clarity. The acceleration comes from Q4. The base voltage is divided and filtered by R28, R29, R27 and C8. The acceleration gain is set by the ratio of R25 to R8. The set point at which the acceleration begins is set by the ratio of

R28/R29 and R27. Generally, the voltage at the base of Q4 is set just above V_{CC} at the low line specification. There is a trade off here between the low line specification and the dimming curve shape.

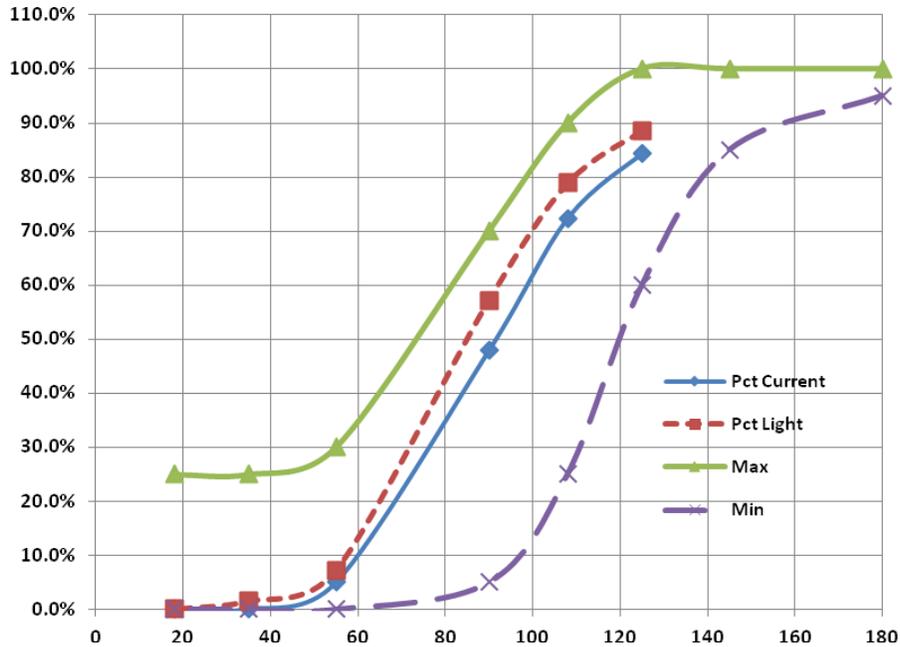


Figure 9. Dimming Curve with Acceleration

The light output and the current have both been normalized at 100% output which is 750 mA dc in this example. Also note in this case, the reason the current does not reach 100% is that the maximum dimmer conduction angle was approximately 125 degrees. The LEDs are more efficacious at the lower current levels. While the curve shape looks correct, it is clearly biased toward the maximum curve. To bring the curve closer to the incandescent curve, we would have to compromise on the low line specification which is 100 Vac for this example.

Other Considerations

While dimming performance is quite good, there is a price for this. There is of course the cost of components and the extra PCB area. The efficiency is also reduced. The baseline efficiency was right at 90% without the preconditioning circuit. The addition of the preconditioning circuit reduced the efficiency to 85%.

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